NUTRIENT IMBALANCIES IN CONIFEROUS STANDS IN SOUTHERN GERMANY

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Two examples of imbalanced nutrition in coniferous stands of southern Germany are described as follows:

a) Induced P and Mg deficiency showed up in a fertilization experiment (O — N — NPKMg) in a pole stand of Scots pine (*Pinus sylvestris* L.) growing on a podzolic soil with pseudogley features derived from layered cretacious substratum. In this case repeated fertilization with only nitrogen resulted in a lowering of foliar P and Mg levels down to threshold values mainly by a dilution effect. This reduction could be avoided by additional PKMg dressings, and the latter treatment yielded the best growth responses.

b) Extreme magnesium deficiency in unfertilized stands of Norway spruce (*Picea abies* Karst.) occurs in the Bavarian Forest at higher altitudes (> 1000 m). It is associated with very low calcium contents in the needles, but with excellent nitrogen and phosphorus nutrition. The stands, growing on acid or podzolic brown forest soils derived from granite and gneiss, exhibit typical deficiency symptoms, premature needle shedding and growth depressions. There is evidence that acid deposition may contribute to this growth disturbance, which seems to be a rather recent phenomenon. Acid rain adds nitrogen to the systems, but may leach calcium and magnesium from needles and soils. Mg deficiency seems to be associated with a decrease in frost hardiness of spruce needles.

Phosphorus and magnesium deficiency in older pine stands

Scots pine (*Pinus sylvestris*) stands in southern Germany often grow on sites, which are poor in N, P, Ca, and Mg and/or are degraded by the interferences of man like burning, grazing or litter raking. Those soils are generally very acid and characterized by unfavorable biologically inactive raw humus. It is well known, that pines on these substrata suffer from N deficiency. Therefore fertilization with N (100—150 kg · ha^{-1} repeated every 5—7 years) is a common amelioration practice in older stands. On the other hand it was assumed hitherto, that the amounts of available P, K, Ca and Mg in the soils although being low — would be sufficient for good pine growth on most mineral soils even after repeated N fertiliz-

ation (Wehrmann 1956, Zöttl and Kennel 1962, Kennel and Wehrmann 1967, Kennel 1967, Kreutzer 1967, Franz and Bierstedt 1975).

In Bavaria there exists only one trial, which, by comparing the effects of fertilization with N alone and with combined NPKMg, gives the possibility to check, whether this earlier conclusion of adequate supply of pines with all other nutrients except N still holds true under all conditions.

Experimental design

The experiment BUL 240 Eichenhänge (FA. Burglengenfeld) was established in 1961 by J. Wehrmann and F. Franz in a pole stand of pines 54 years old (site class IV. 2 according to yield table of Wiedemann 1943, moderate thinning). It grows on a podzolic brown forest soil (spodic dystrochrept), showing pseudogley features in deeper horizons, which is derived from sandy and clayey cretaceous sediments. The trial involves three treatments (O; N; NPKMg) replicated twice.

Table 1. Description of fertilizer treatments in experiment BUL 240 Eichenhänge (nutrient amounts in kg/ha).

Date	Treatment	
	N	NPKMg
5.61	100 N 66 Ca	100 N 79 P 116 K 30 Mg 290 Ca
6.62	100 N 66 Ca	100 N 79 P 116 K 30 Mg 290 Ca
5.63	100 N 66 Ca	100 N 79 P 232 K 60 Mg 290 Ca
5.72	120 N 66 Ca	120 N 79 P 208 K 48 Mg 290 Ca
Total	420 N 264 Ca	420 N 316 P 672 K 168 Mg 1160 Ca

N as kalkammonsalpeter (4 × 5 dt/ha); P as superphosphate (4 × 10 dt/ha); KMg as patentkali (30 dt/ha); Ca in kalkammonsalpeter and superphosphate

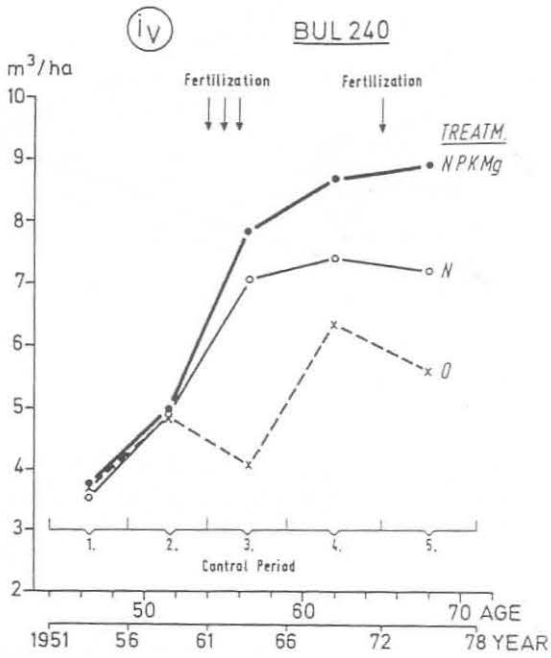

Figure 1. Volume increment (total stemwood including bark) of experimental units.

Table 1 describes the experimental design in detail; for the evaluation techniques see Preuhsler and Rehfuess 1982.

Growth reactions

Figure 1 exhibits the growth reactions during five measuring periods, each of which lasted 5 or 6 years. The angle points of each curve indicate the average annual volume increment (total stem wood including bark) within one particular period.

During the ten years prior to the start of the experiment pine growth was rather poor and very similar on all plots irrespective of the experimental unit. The application of NPKMg at 4 different dates (last application 1972!) immediately improved volume growth, and a raised growth level was maintained until today, although it seemed to diminish slightly during the last control

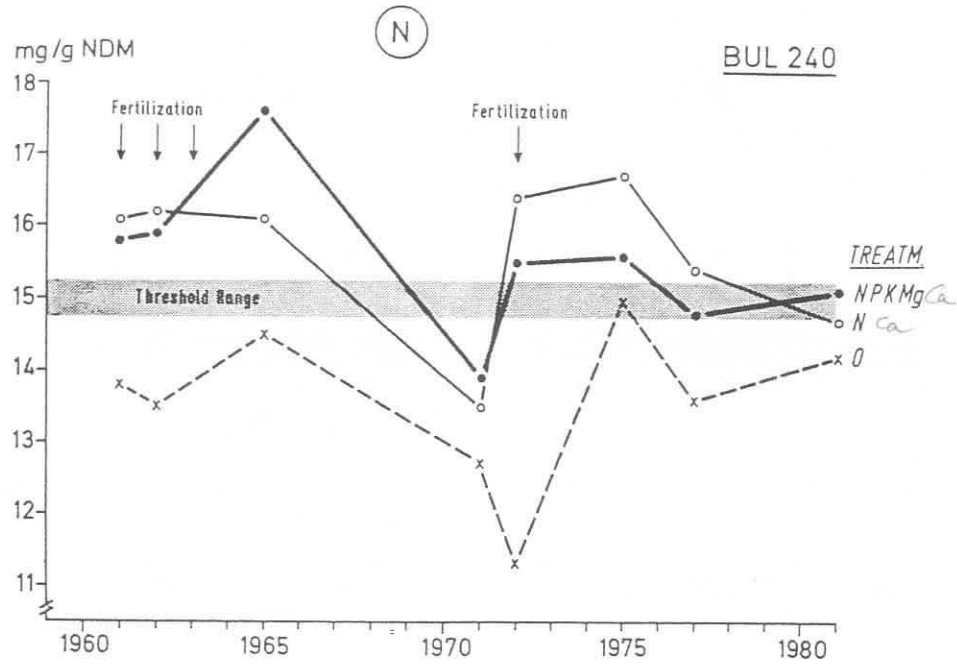

Figure 2. Nitrogen contents of half year old pine needles.

period. Even in this final phase the volume growth in NPKMg treatment amounted to about 9 $m^3 \cdot ha^{-1} \cdot a^{-1}$, which is an additional increment of 3,4 $m^3 \cdot ha^{-1} \cdot a^{-1}$, or 60 % as compared with control stands (5,6 $m^3 \cdot ha^{-1} \cdot a^{-1}$).

Application of N alone at the very beginning of the trial enhanced volume growth to about the same extent as complete fertilization (NPKMg). In the longer run, however, this treatment more and more revealed itself to be inferior, and during the last monitoring period the additional growth caused by N application alone only reached 1,6 $m^3 \cdot ha^{-1} \cdot a^{-1}$ or 29 % of the growth level of control pines.

Foliar nutrient levels

During the first phase of experimentation from 1961—63, both fertilizer treatments considerably improved the N nutrition of the pines, and this effect lasted at least until 1965 (Fig. 2). Between 1964 and 1971 no fertilizer was spread, since the response to the initial application should be monitored. Therefore the N contents of pine needles on all ameliorated plots decreased. Although trees, which had earlier received N, still were superior, they once more started to suffer from N deficiency. The repeated fertilization in May 1972 immediately raised the N contents of pine needles to a sufficient level of supply (15—16 mg N/g), treatment "N" producing the highest levels. The rapid enhancement of volume growth during the first few years of experimentation, occurring in similar ways in both the N and the NPKMg treatment, therefore is supposed to have been caused mainly by improved N supply.

Application of N alone, however, was associated with rather low P contents of pine needles (1,2—1,3 mg/g). Foliar P levels in this treatment were lower as compared with those of control stands and varied within the range of P deficiency. The N/P ratios increased to unusually high values between 11 and 14 (Fig. 3). This decrease of P supply by treatment "N" presumably was due to a dilution effect. Similarly the Ca and Mg contents of pine needles declined after application of N alone during the years from

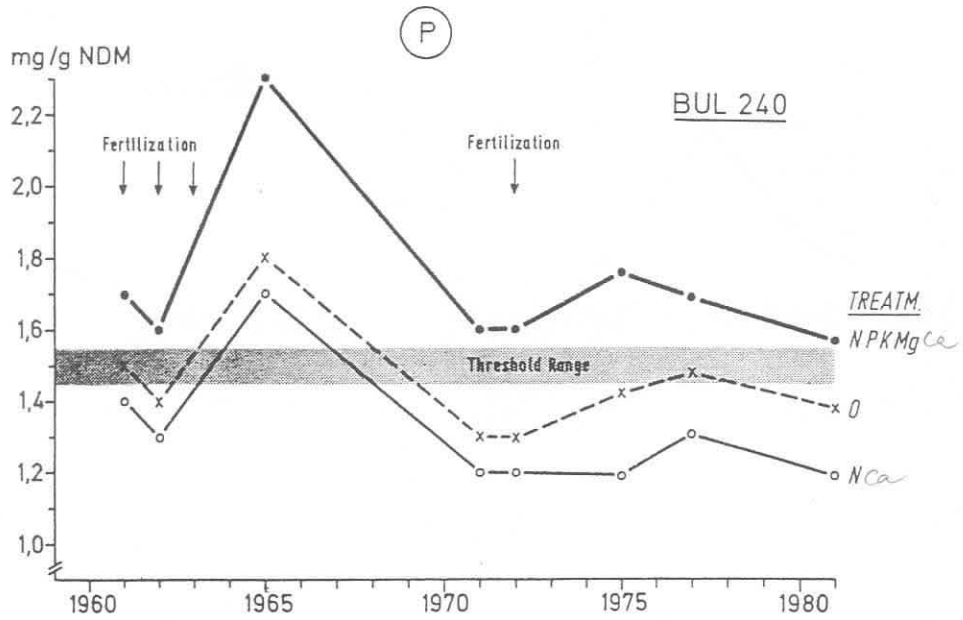

Figure 3. Phosphorus contents of half year old pine needles.

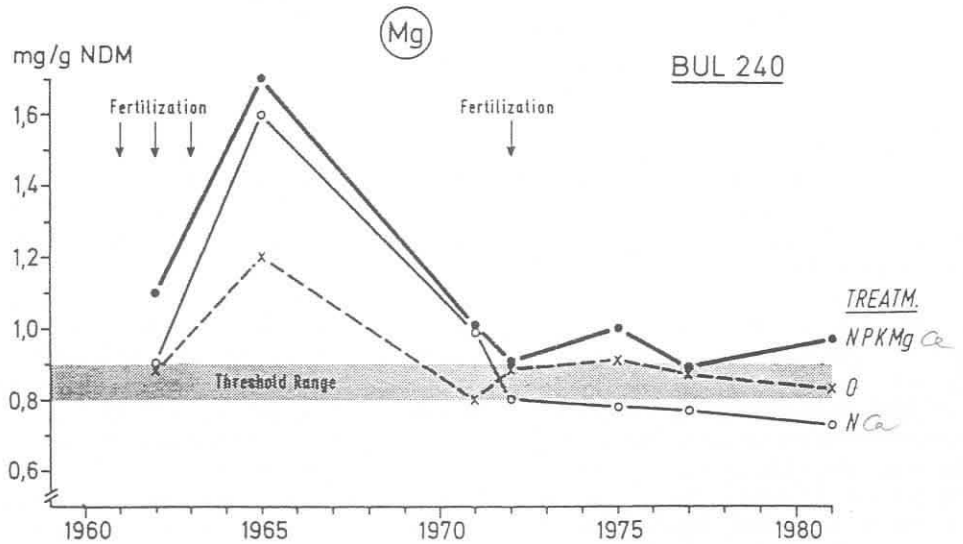

Figure 4. Magnesium contents of half year old pine needles.

1972 onward, and the threshold range for Mg deficiency was also undercut (Fig. 4).

The NPKMg fertilization on the contrary maintained an adequate supply of P (1,6—1,7 mg/g) and Mg (0,9—1,1 mg/g) during the total period of experimentation, and the N/P ratios remained low (9—10).

Consequences

Therefore it is recommended to change from pure N addition to well-balanced NPMg (KCa) fertilization on more sites than was anticipated before (cf. Tamm et al. 1974, Kern and Moll 1976). This trend is expected to be even more pronounced by

the long term effects of acid precipitation, which imports considerable amounts of nitrogen into forest ecosystems but may enhance their Mg, Ca and K losses (Abrahamsen 1980).

Growth disturbances of Norway spruce (Picea abies Karst.) in eastern Bavaria

Description of decline phenomena

Since about 1980, Norway spruce stands of all age classes (5—250 years) at higher elevations (>1000 m, mean annual precipitation >1250 mm) of the Bavarian Forest (Bayerischer Wald) and in the Upper Palatian Forest (Oberpfälzer Wald) along the border to the CSSR show reduced vitality and decline phenomena, the intensity of which has increased in the meantime. The symptoms are as follows:

Chlorosis and succeeding necrosis of older needles starting at needle tips, normally more pronounced on the upper (lighted) side of the needle; premature shedding of older needles; decreasing crown density starting at the inner and lower crown portions; depressed shoot growth and year ring width; rather rapid death of single trees or small tree groups, whereas adjacent trees seem to remain unaffected; decreasing stand density.

In the Bavarian Forest, where a belt of natural spruce forests occurs between 1150 m and the summits of the mountains (top elevation 1458 m), both autochthonous old growth stands and spruce plantations of unknown provenance are affected, the latter however seem to suffer more. Predominant, codominant and suppressed trees may show the same symptoms. The decline phenomena are widespread on acid to podzolic brown forest soils (dystrochrepts) and shallow podzols (ferrods) derived either from granite or gneiss slope sediments. These periglacial deposits are characteristically stratified and divided into a superficial layer (30—80 cm) loose and rich in stones or blocks and a deeper stratum which is dense, compact and exhibits a platy structure as well as an orientation of stony fragments. Root development is generally restricted to the upper layer and hence may be rather shallow.

Results of foliar analyses

In November 1981 we compared, by means of foliar analysis, affected spruces with apparently healthy neighbours in three representative stands (1 older stand and 2 young plantations) on acid to slightly podzolic brown forest soils (2 derived from paragneiss 1 from granite). In each stand 3—5 pairs of trees were selected. Each pair involved 2 adjacent trees of similar age, height, diameter and stand position, obviously growing at the same microsite conditions. One of those trees showed severe symptoms, whereas the second was apparently free from decline phenomena. Needles of all age classes were sampled and analyzed from the uppermost as well as from the 5th or 7th whorl.

In all stands investigated the nitrogen and phosphorus nutrition of both diseased and healthy trees was excellent (Tables 2 and 4). The potassium supply was generally adequate, although healthy trees tended to have slightly more K in their needles. There was evidence, that the Fe, Mn, Cu and Zn levels of unaffected trees normally exceeded those of neighbouring diseased spruces. This observation holds especially true for Mn in sample stand "Dreisessel" and for Zn in all stands (Tables 3 and 5). Nevertheless declining trees presumably didn't suffer from trace element deficiency, since foliar contents normally varied above the threshold

Table 2. Macronutrient contents in the needles of healthy and diseased old Norway spruce trees. Study area Luchsplatzl/FA. Bodenmais Podzolic brown forest soil derived from paragneiss.

Element		Diseased trees Min.	Max.	$\bar{x}$	Healthy trees Min.	Max.	$\bar{x}$
		Year's growth 1981					
N	mg/g	16,2	17,7	17,0	14,3	16,9	15,9
P		1,6	1,8	1,7	1,6	2,1	1,9
K		3,6	5,3	*4,4*	5,4	6,1	*5,7*
Ca		0,8	1,6	*1,2*	1,4	2,0	*1,7*
Mg		0,39	0,68	*0,51*	0,58	0,81	*0,69*
		Year's growth 1978					
N	mg/g	13,0	14,2	13,7	12,0	14,2	13,2
P		1,0	1,1	1,0	1,2	1,3	1,2
K		3,5	4,6	*4,1*	4,0	5,9	*4,8*
Ca		1,8	3,9	*2,5*	2,7	5,6	*4,0*
Mg		0,17	0,29	*0,24*	0,27	0,84	*0,52*

Data of three tree pairs, each involving one unaffected and one diseased tree with comparable dimensions and sociological position. Needles originated from the 7th whorl. Sampling date 24.11.1981.

Table 3. Micronutrient contents in the needles of healthy and diseased old Norway spruce trees. Study area Luchsplatzl/FA. Bodenmais podzolic brown forest soil derived from paragneiss.

Element	Diseased trees Min.	Max.	$\bar{x}$	Healthy trees Min.	Max.	$\bar{x}$
			Year's growth 1981			
Fe µg/g	35	40	37	40	52	45
Mn	112	187	158	173	193	181
Cu	3	7	5	3	5	4
Zn	7	18	13	16	24	20
			Year's growth 1978			
Fe µg/g	59	68	64	64	92	74
Mn	168	209	194	178	306	221
Cu	3	4	3	2	5	4
Zn	8	12	10	12	20	15

For comments see Table 2.

Table 4. Macronutrient contents in the needles of healthy and diseased young Norway spruce trees. Study area Dreisessel/FA. Neureichenau podzolic brown forest soil derived from granite.

Element	Diseased trees Min.	Max.	$\bar{x}$	Healthy trees Min.	Max.	$\bar{x}$
			Year's growth 1981			
N mg/g	16,7	25,2	20,0	15,6	19,7	17,9
P	1,9	3,1	2,2	1,7	2,2	2,0
K	4,9	6,8	5,8	6,0	7,2	6,3
Ca	1,11	2,15	1,71	2,15	3,14	2,77
Mg	0,17	0,29	0,21	0,30	0,47	0,40
			Year's growth 1978			
N mg/g	12,6	15,9	14.0	12,4	14,6	13,2
P	1,5	2,5	1,8	1,3	1,4	1,3
K	4,6	6,2	5,3	4,0	4,8	4,4
Ca	3,6	4,7	4,0	5,3	6,8	5,9
Mg	0,13	0,23	0,16	0,26	0,35	0,29

Data of four tree pairs, each involving one unaffected and one diseased tree with comparable dimensions and sociological position. Needles originated from the 3th whorl. Sampling date 23.11.1981.

ranges. Al contents of spruce needles were not significantly different between healthy and diseased specimens.

The most striking difference, on the contrary, occurred with magnesium and calcium. In all sample stands investigated, the level of supply of these elements was in general very low. In each particular pair of sample spruces, the healthy tree showed higher Mg and Ca contents in the leaves than its diseased neighbour.

The affected trees all suffered from extreme Mg deficiency (cf. Zech and Popp 1983), and this shortage was normally more pronounced in older than in younger needles

Table 5. Micronutrient contents in the needles of healthy and diseased young Norway spruce trees. Study area Dreisessel/FA. Neureichenau podzolic brown forest soil derived from granite.

Element	Diseased trees Min.	Max.	$\bar{x}$	Healthy trees Min.	Max.	$\bar{x}$
			Year's growth 1981			
Fe µg/g	45	68	52	36	62	52
Mn	158	355	*289*	523	848	*665*
Cu	3	4	4	4	7	5
Zn	16	24	20	21	47	37
Al	54	129	102	72	112	89
			Year's growth 1978			
Fe µg/g	74	124	92	62	101	*78*
Mn	438	632	*561*	674	1281	*1044*
Cu	4	5	4	3	4	4
Zn	21	46	29	26	48	32
Al	183	288	246	108	331	182

For comments see Table 4.

and on soils derived from granite — inherently low in Mg — as compared with paragneiss substrata containing at least moderate amounts of this element (Table 6).

It is difficult to evaluate the Ca data, since the threshold values for this element and for older Norway spruce stands are not yet well established. Nevertheless it is quite sure, that the Ca levels observed are very low in comparison with the results of all inventories on the nutritional status of Norway spruce carried out in southern Germany (Strebel 1960, Rehfuess and Moll 1965, Rehfuess 1969 and 1973, Elling et al. 1976) and quite near to the deficiency levels as reported by Morrison (1974) and Van den Burg (1979). Electron probe microanalysis (EPMA) combined with scanning electron microscopy (SEM) of representative individual needles (site Luchsplatzl; lower parts of the crown; N aspect; needle age class 4; sampling in March 82) detected a marked accumulation of calcium in the immediate surroundings of the stomata of healthy spruces, whereas this peak was less pronounced with diseased trees. This shortage of Ca may hinder the normal functions of stomata. The potassium distribution was not affected. Unfortunately the sensitivity of the x-ray technique used was not strong enough to also localize Mg on and within the leaves.

Needles from healthy spruce trees (site Luchsplatzl; whorl 7; needle age class 1—5; sampling date Nov. 81), irrespective of age,

Table 6. Reaction and K, Ca and Mg contents of representative soil forms in the study area.

Site and soil form	Horizon	Depth cm	pH H_2O	pH $CaCl_2$	K_T	Ca_T mg/g	Mg_T
Luchsplatzl (C_3)							
Podzolic brown	OF	9— 2	4,38	3,45	1,6	0,58	0,27
forest soil der.	OH	2— 0	4,15	3,40	1,8	0,91	0,37
from paragneiss	A_{eh}	0—10	4,37	3,70	13,1	5,53	3,35
	A_hB_v	10—21	4,35	3,95	15,4	5,56	4,12
	B_v	21—41	4,42	4,15	16,0	6,78	3,98
	II B_v	41—68	4,57	4,35	17,2	7,18	5,47
	C_vB_v	68—94	4,67	4,60	19,2	8,50	6,96
Dreisessel (A_1)							
Podzolic brown	OF	7— 3	4,45	3,70	3,0	1,88	0,54
forest soil der.	OH	3— 0	4,13	3,25	15,1	1,52	0,63
from granite	A_{eh}	0—28	4,46	4,05	28,0	0,79	0,76
	$(Go)A_hB_v$	28—49	4,60	4,25	30,0	1,04	1,00
	B_v	49—	4,76	4,45	35,0	2,01	1,33

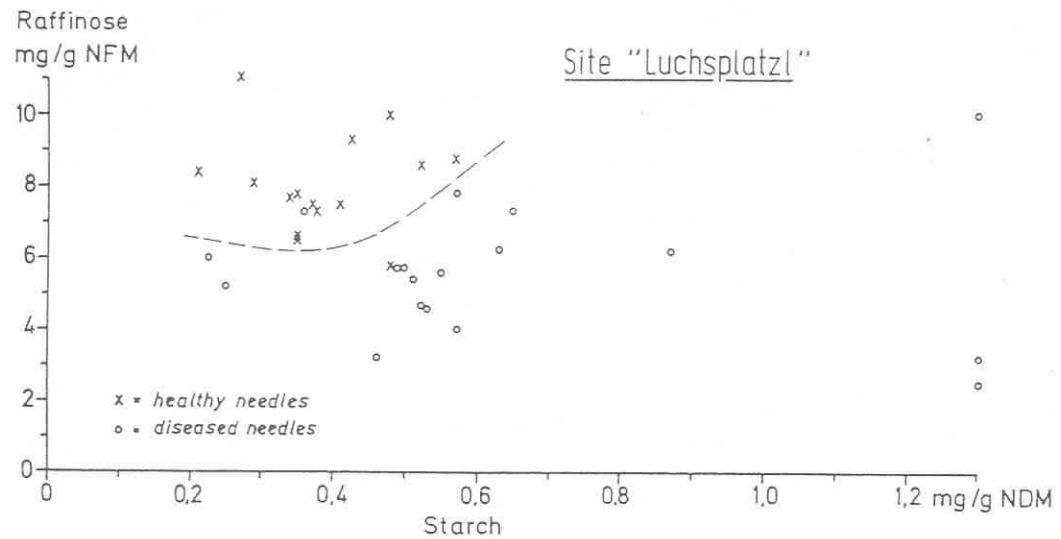

Figure 5. Scatter diagram for raffinose vs. starch contents in spruce needle fresh matter.

generally contained less starch, but more raffinose as compared with diseased neighbours. This significant shift of the starch/raffinose ratio (Fig. 5) may indicate a decrease in frost hardiness of the foliage of affected spruces (Kandler et al. 1979, Vogl et al. 1972, Ranft et al. 1979).

Conclusions

From these preliminary observations we have derived a working hypothesis to explain the recent Norway spruce decline at higher elevations in forest regions of eastern Bavaria. It may hold true only, if root pathogens or abiotic agents damaging the roots primarily are not involved — in fact until now those were not yet detected:

Affected trees suffer from severe Mg deficiency; they are also poorly supplied with Ca. The deficiency symptoms are most pronounced under conditions of intensive illumination, where the deterioration of chlorophyll is increased by photooxidation. On the other hand the N and P nutrition of both healthy and diseased trees is excellent. This finding may indicate, that affected spruces don't exhibit any general and drastic reduction of the absorbing capacity of their root systems in relation to the foliage mass and at the very beginning of the disease.

Since this shortage of magnesium and calcium in spruce occurs on substrata differing considerably in the contents of both elements, we don't feel that a depletion of the soils is the most prominent factor causing the deficiency. We rather suppose this recent deficiency to be mainly a consequence of enhanced dissolution of Mg and Ca from the needles either by SO_2/SO_3— dissolving in the water films on the needles and in the free space and forming H_2SO_3/H_2SO_4— or by strong acids already diluted in the precipitation (cf. Horntvedt 1979, Horntvedt et al. 1980, Jacobson 1980, Tukey 1970). This assumption is supported by our accidental observation, that under special weather conditions gypsum cristals appear in and around the antestomatal cavities, and that they are significantly more numerous on the relatively Ca rich foliage of healthy than on that of affected trees. The Mg and Ca deficiency is accelerated by the fact, that wet and dry deposition in a forest opening imports rather high amounts of N and S in the area under investigation (~ 20 kg N; 19 kg SO_4—S and 0,5 kg $H^+ \cdot ha^{-1} \cdot a^{-1}$ in 1980/81; pH 4,47) but only few Mg and Ca (~1 and ~5 $kg \cdot ha^{-1} \cdot a^{-1}$, respectively; Dunkl 1982). Due to the fact that the soils are rather rich in potassium, this element seems to be replaced very rapidly by root uptake (cf. Tukey 1970, Horntvedt 1979). The absorption of calcium and magnesium, however, may be not efficient enough to counteract the leaching from the foliage.

The insufficient supply of Norway spruce with magnesium and calcium should be most severe on soils derived from granite, poor in earth alkaline elements, on strongly podzolized substrata and on those allowing only shallow rooting in a stony slope deposit. It will be aggravated by leaching of both elements from the top horizons as increased by acid deposition (Abrahamsen 1980, Rehfuess 1981).

The magnesium deficiency of needles may reduce their physiological activities in general and especially their frost hardiness. Therefore sudden and extreme temperature falls after warm period in early spring and/or during mid-winter may presumably cause or intensify chlorosis and premature death of needles and trees. The older needles should be affected more than younger ones, since they contain less Mg and K and are photosynthetically less effective. It should be stated that the symptoms of Norway spruce decline are very similar to those of a late frost damage in April 1981 in Sitka spruce plantations in western Scotland as reported by Redfern (1982, pers. communication). The suggested interaction of acid deposition, nutritional status, frost hardiness and frost events would explain the extreme tree-to-tree variation with regard to the intensity of the disease observed in our sample stands as well as the rather sudden outbreak of the disease. Leaves which are injured by adverse climate or by nutritional or physiological disorders are *vice versa* more susceptible to leaching than those from healthy and vigorous plants (Tukey 1970).

It should be mentioned, that spontaneous temperature falls occurred in April 1980 and 1981 as well as in the night from December 31, 1978 to January 1, 1979. Klimo (1979) observed, that the needle fall in a spruce stand in Moravia rised during April June after this latter event to 1500 kg/ha as compared with 550—730 kg/ha in the years before.

A depression of gas exchange and photosynthesis due to Mg and Ca deficiency and a reduction of needle mass may decrease the supply of roots with carbohydrates, thus gradually slowing down root activity and nutrient or water absorption. A general decline of tree vitality may be the result as well as an increased susceptibility to root pathogens, to needle cast fungi and to insects feeding on the foliage.

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References

ABRAHAMSEN, G. 1980. Acid precipitation, plant nutrients and forest growth. Proc. Intern. Conference on Ecological Impact of Acid Precipitation, Sandefjord, Norway, p. 58—63.

VAN DEN BURG, J. 1979. Calcium status of Corsican pine (Pinus nigra ssp. laricio) and top-dying. Rapport Nr. 212 Rijksinstituut "De Dorschkamp" Wageningen.

DUNKL, J. 1982. Der Stoffeintrag mit dem Freiland- und Bestandesniederschlag an drei Stationen in verschiedenen Waldgebieten Bayerns. Dipl.Arbeit Univ. München.

ELLING, W. et. al. 1976. Nationalpark Bayerischer Wald. Klima und Böden, Waldstandorte. Bayer. Staatsmin. f. Ern., Landw. u. Forsten.

FRANZ, F. & BIERSTEDT, W. 1975. Wirkung großflächiger Flugzeugdüngung mit Kalkammonsalpeter auf den Volumenzuwachs von Kiefernbeständen im Bayerischen Forstamt Bodenwöhr/ Oberpfalz Forstwiss. Cbl. 94: 310—314.

HORNTVEDT, R. 1979. Leaching of chemical substances from tree crowns by artificial rain. Mitt. IUFRO Tagung s. 2.09 "Luftverunreinigung" Ljubljana 1978. p. 115—125.

— , DOLLARD, G. J. & JORANGER, E. 1980. Effects of acid precipitation on soil and forest. 2. Atmosphere — vegetation interactions. In: Drablos, D. & Tollan, A. (eds.), Ecological Impact of acid precipitation, p. 192—193.

JACOBSON, J.S.M. 1980. The influence of rainfall composition on the yield and quality of agricultural crops In: Drablos, D. & Tollan, A. (eds.), Ecological Impact of acid precipitation. p. 41—46.

KANDLER, O., DOVER, C. & ZIEGLER, P. 1979. Kälteresistenz der Fichte. I. Steuerung von Kälteresistenz, Kohlenhydrat- und Proteinstoffwechsel durch Photoperiode und Temperatur. Ber. Dtsch. Bot. Ges. 92: 225—241.

KENNEL, R. 1967. Ertragskundliche Ergebnisse neuer Düngungsversuche in Kiefern-, Fichten- und Buchenbeständen Bayerns. Forstwiss. Cbl. 86: 13—28.

— & WEHRMANN, J. 1967. Ergebnisse eines Düngungsversuchs mit extrem hohen Stickstoffgaben in einem Kiefernbestand geringer Bonität. XIV IUFRO-Kongress München Bd. VI: 216—231.

KERN, K.G. & MOLL, W. 1976. Melioration von streugenutzten Standorten unter Anwendung von Stickstoff-Depot-Dünger Allg. Forst- u. Jagztg. 147: 192—200.

KLIMO, E. 1979. Nutrient cycling within the ecosystem of a man-made spruce forest. In: Klimo, K. (ed.) Proc. Symp. "Stability of spruce forest ecosystems", Brno 1979.

KREUTZER, K. 1967. Ernähungszustand und Volumenzuwachs von Kiefernbeständen neuer Düngungsversuche in Bayern. Forstwiss. Cbl. 86: 28—53.

MORRISON, J.K. 1974. Mineral nutrition of conifers with special reference to nutrient status interpretation. A review of literature. Dept. Environment, Can. Forestry Service Publ. No. 1343, Ottawa.

PREUHSLER, T., & REHFUESS, K.E. 1982. Über die Melioration degradierter Kiefernstandorte (Pinus sylv. L.) in der Oberpfalz. Forstwiss. Cbl. 101 (in press).

RANFT, H. et al. 1979. Untersuchungen zum Zusammenwirken von Immissions- und Frosteinfluß im Fichten-Rauchschadgebiet. Beitr. f. d. Forstwirtsch. 4: 160—165.

REHFUESS, K.E. & MOLL, W. 1965. Orientierende Untersuchungen über den Ernährungszustand von Fichtenbeständen auf Jungmoräne in Oberschwaben. Allg. Forst- u. Jagdztg. 136: 211—223.

— 1969. Ernährungszustand und Kernfäulebefall älterer Fichtenbstände auf der Schwäbischen Alb Mitt. Verein Forstl. Standortskunde u. Forstpflanzenzüchtung 19. 6.

— 1973. Kernfäulebefall und Ernährungszustand älterer Fichtenbestände (Picea abies Karst.) im Wuchsgebiet "Baar-Wutach". Mitt. Verein Forstl. Standortskunde u. Forstpflanzenzüchtung 22.

— 1981. Über die Wirkungen der sauren Niederschläge in Waldökosystemen. Forstwiss. bl. 100: 353—400.

STREBEL, O. 1960. Mineralstoffernährung und Wuchsleistung von Fichtenbeständen in Bayern. Forstwiss. Cbl. 79: 17—42.

TAMM, C.O. et al. 1974. The optimum nutrition experiment Stråsan. A brief description of an experiment in a young stand of Norway spruce (*Picea abies* Karst.). Research Notes, Dept. Forest Ecology and Forest Soils No. 17.

TUKEY, H.B. 1970. The leaching of substances from plants Ann. Rev. Pl. Phys. 21: 305—324.

VOGL, M. et al. 1972. Untersuchungen zur individuellen Rauch- und Frostresistenz von Fichten aus einem Schadgebiet im oberen Erzgebirge. Archiv Pflanzensch. 8: 233—243.

WEHRMANN, J. 1959. Mineralstoffernährung von Kiefernbeständen (Pinus silv.) in Bayern. Forstwiss. Cbl. 78: 129—150.

ZECH, W. & POPP E. 1983. Magnesiummangel, einer der Gründe für das Fichten- und Tannensterben in NO-Bayern. Forstwiss. Cbl. 102 (in press).

ZÖTTL, H. & KENNEL, R. 1962. Die Wirkung von Ammoniakgas- und Stickstoffsalzdüngung in Kiefernbeständen. Forstwiss. Cbl. 81: 65—91.

Total of 28 references